REVIEW

Physiology, biomechanics and injuries in table tennis: A systematic review

Physiologie, biomécanique et blessures au tennis de table : une revue systématique

C. Ferrandez[a], T. Marsan[a,*], Y. Poulet[a], P. Rouch[a], P. Thoreux[a,b], C. Sauret[a]

[a] *Arts et Métiers Institute of Technology, Institut de Biomécanique Humaine Georges Charpak, 151, boulevard de l'Hôpital, 75013 Paris, France*
[b] *Université Paris 13, Sorbonne Paris-cité, hôpital Avicenne, AP—HP, 93017 Bobigny, France*

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Summary
Objectives. — Table tennis is a widely practiced sport, often described as a reaction sport. Therefore, players need to practice extensively that may expose them to overuse injuries. For optimizing training with limitation of the injury risk, the knowledges of table tennis physiology, biomechanics and epidemiology are of primary interest.
Methods. — For that purpose, a literature review has been made through a systematic search on three scientific databases. Overall, table tennis physiology is complex due to intense and intermittent efforts. It results that some technological challenges still need to be addressed to accurately quantify this physiology. Besides, current rules changes may modify the table tennis physiological requirements.
Results. — Findings in neurophysiology tend to define table tennis as an anticipation sport rather than a reaction sport and higher occulo-motor skills were found in table tennis population with respect to average population. Regarding biomechanics, some rare studies have been done but none had investigated the energy flow between the upper- and the lower-body, which would be interesting to understand how the energy generated by the footwork contributes to racket velocity.
Conclusion. — Finally, epidemiological studies lack of details on injury locations and diagnosis. These data could be of high interest to improve medical and training care.

* Corresponding author.
E-mail address: thibault.marsan@ensam.eu (T. Marsan).

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Résumé
Objectifs. — Le tennis de table est un sport très pratiqué, souvent décrit comme un sport de réaction. De ce fait, les joueurs ont besoin de beaucoup pratiquer, ce qui peut les exposer à des blessures. Pour l'optimisation de l'entraînement, tout en réduisant le risque de blessure, les connaissances de la physiologie, de la biomécanique et de l'épidémiologie du tennis de table sont primordiales.
Méthode. — Dans ce but, une revue systématique de la littérature a été effectuée au travers de trois bases de données. Globalement, la physiologie du tennis de table est complexe à cause d'efforts intenses et intermittents. Il reste alors des challenges techniques à relever pour quantifier précisément cette physiologie. De plus, certains changements dans le règlement tendent à faire évoluer les exigences physiologiques du tennis de table.
Résultats. — Les résultats en neurophysiologie tendent à définir le tennis de table comme un sport d'anticipation plutôt qu'un sport de réaction et des compétences oculomotrices plus élevées ont été trouvées en comparaison à la population moyenne. En ce qui concerne la biomécanique, quelques rares études ont été réalisées mais aucune n'a étudié les contributions d'énergie mécanique dans l'ensemble du corps, ce qui permettrait notamment de mieux comprendre l'effet de la puissance des membres inférieurs sur la vitesse de la raquette et de la balle.
Conclusion. — Finalement, les études épidémiologiques manquent de détails sur le diagnostic et la localisation des blessures. Ces données pourraient être de grand intérêt pour améliorer les soins médicaux et la surveillance de l'entraînement.

1. Introduction

Table tennis is a racket sport practiced by more than 260 million players around the world, among which 33 million people are registered within the different national federations. Table tennis is often characterized as a reaction sport due to the high velocity of the ball and the short distance between the players. Indeed, players have a very short period of time to return the ball (less than 1 second). During this short delay, table tennis players have to analyse the characteristics of the incoming ball, to decide where to return it and to move to an adequate hitting position to perform the stroke gesture.

To play at a high performance level, the specific gestures must approach a reflex gesture, requiring repetitions through an extensive training, which may expose the athlete to overuse injuries [1]. Hence, there is a need of optimizing the training to improve performance while limiting the risk of injuries. For that purpose, physiology, biomechanics and epidemiology are of primary interest. Some literature review were recently published on match analysis [2] or physiological demand [3] but there is still a lack of evidence-based summary on current knowledge about the physiology (excepted the physiological demand) and biomechanics of table tennis. In addition, no meta-analysis has been made on related injuries in table tennis.

Therefore, this review article attempts to provide a systematic review search on these three fields, i.e. table tennis physiology, biomechanics and injuries; and to draw future research directions to improve performance while limiting injuries.

2. Material and methods

2.1. Search strategy

A systematic search of the relevant literature, following the PRISMA method (Fig. 1), was performed to identify articles published before December 2018 in the three fields of research for the study: physiology, biomechanics, and injuries in table tennis. PubMed, Scopus and IEEE Xplore databases were searched for relevant articles. The requests used in those databases were as following:

- for the physiology: ''table tennis'' and ''physiolog*'' or ''athletic performance'' or ''exercise test'' or ''metabolism''or ''aerobic or anaerobic'' or ''oxygen consumption'' or ''neurolog*'' or ''motion perception'';
- for biomechanics: ''table tennis'' and ''biomechanic'' or ''kinematic'' or ''dynamic*'' or ''kinetic*'' or ''angle or speed*'' or ''rotation*'' or ''moment*'' or ''force or top-spin'' or ''forehand'' or ''backhand'' and not ''psycholog*'' or ''robot*'' or ''mental*'';
- for the injuries: ''table tennis'' and ''injury*'' or ''illness*'' or ''sports'' and ''injuries'' or ''pathology*'' or ''disease*'').

2.2. Eligibility criteria and study selection

Only publications — full paper or review — written in English and published before December 2018 were included in this study. Publications in which table tennis was not the main

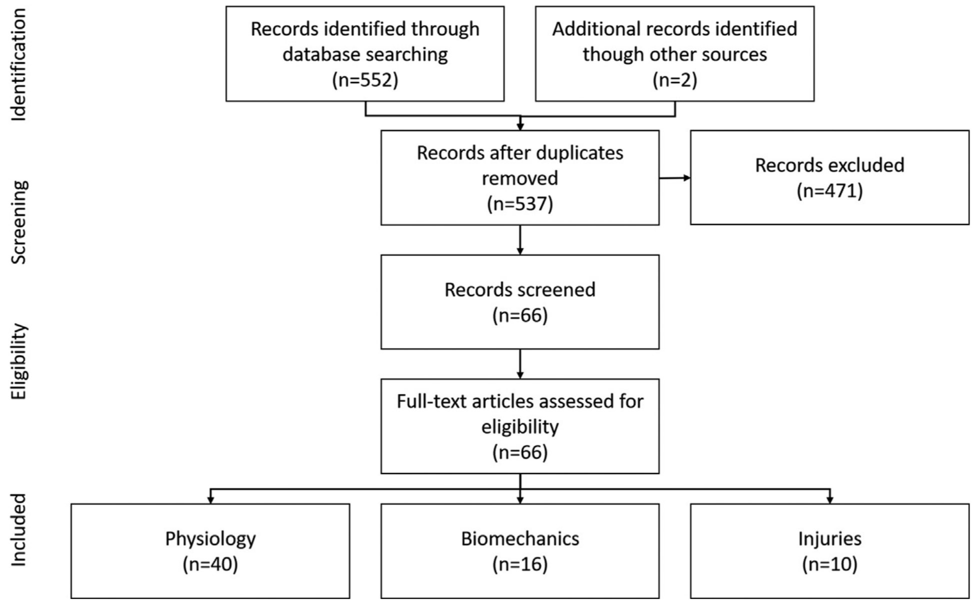

Figure 1 Workflow adapted from the PRISMA method [65] showing the method to identify and select full-text articles for eligibility.

sport studied were excluded. Only able-bodied players were considered, regardless of their level (recreational to elite).

Study selection was performed by two independent reviewers, which would avoid to abusively eliminate an article, based on the abstracts and keywords.

The inclusion criteria for the physiology section was the physiological responses, the energetic demand, aerobic and anaerobic metabolism, ophthalmic behavior, reaction-time, and motion perception while exclusion criteria were the psychology, the focus on performance only and the mention of table tennis as an example. For the biomechanics, inclusion criteria were the kinematics and kinetics of the table tennis player, and the muscle activation. The articles focusing on ball and racket characteristics, psychopathology, ball launcher robot design, and ball trajectory were excluded. The inclusion criteria for the injury section were acute and chronic pain and traumatology during the practice. Common acute and chronic disease as well as movement analysis were excluded from this section.

2.3. Quality assessment

The quality assessment of the articles was performed based on the checklist developed by [4]. Quotation includes nine criteria such as: description of participant's characteristics and sampling method, presentation of the inclusion/exclusion criteria, evaluation of study design suitability and measurement of key-dependent variables, and description of the study limitations; resulting in a maximum of nine points per article.

3. Results

The initial search returned respectively 196, 292, and 68 articles for the physiology, biomechanics and injuries requests. Removing duplicates resulted in 182, 288, and 67 remaining articles, respectively. After selecting articles based on the inclusion/exclusion criteria previously described, 40, 17 and 10 articles were respectively considered for review.

Results are presented below according to the search field.

3.1. Physiology

After analyzing the topics of the 40 considered articles, they were sorted out into three sub-categories: cardiorespiratory (11 articles), neurophysiology (17 articles), and ophthalmic physiology (12 articles). Article quality assessment resulted in a mean grade of 5.1/9, and ranged from 2 to 7.5. Overall, the design and patient characteristics were well described but study limitations were rarely reported.

3.2. Cardiorespiratory

Regarding the 10 articles included in this sub-category, research focused on the description of table tennis temporal characteristics, physiological demand and specific table tennis physiological test. Studies showed that rallies were short (3.5 seconds in average) interspersed with short breaks (8 to 20 seconds) but resulting in an effort-and-rest (E:R) time ratio (effort time over rest time) lower than 1. Moreover, elite table tennis players (national and international levels) exhibited a lower E:R ratio than within regional experience players, due to longer resting times [3].

These time characteristics result in a complex physiological demand with intermittent profile. Some authors estimated that the metabolic demand was mainly aerobic (96.5%), completed with minor contributions of phosphocreatine breakdown (2.5%) and glycolytic energy (1%) [3]. However, at high level, the contribution of the phosphocreatine breakdown is predominant while the aerobic system is relied on to recover the anaerobic stores used during the intense rallies [5]. Also, a higher respiratory compensation point (RCP) — defined as the point of increase of both ventilatory equivalents of O_2 (VE/VO_2) and CO_2 (VE/VCO_2) — was found in elite players. This is explained by a higher rate of energy restoration during the resting periods, allowing elite players to maintain a higher intensity than lower level players [5]. Comparison between elite and regional players in competition showed no difference on heart rate (HR), oxygen consumption (VO_2) and blood lactate concentration [3]. Despite the higher rallies intensity in elite player, the longer resting time allowed them to compensate.

Because of the complexity of the metabolic demand, which is due to the intermittent nature of the activity, some authors tried to develop physiological tests, dedicated for table tennis. Indeed, among the different parameters measured during classical maximal VO_2 tests (i.e. on a treadmill or on a cycling ergometer), only the blood lactate concentration on the cycle ergometer was relied to the table tennis performance [3]. Specific incremental tests with a ball launcher robot were developed to test the maximal oxygen uptake during table tennis practice. However, data comparison of HR, VO_2, respiratory quotient and lactate do not correspond to the ones obtained during cycling, running or rowing physiological testing [3]. One of the main limits was the inability to obtain maximal VO_2 and lactate values. According to the different authors, more research needs to be performed to develop a specific table tennis physiological test.

Studying the energetic demand and the physical activity level is also an important topic for nutritional management in athlete. Looking at the Compendium of Physical Activities, table tennis is classified as a moderate physical activity with a 4.0 metabolic equivalent (MET), similarly to volleyball and baseball. However, using an indirect calorimetry method (i.e. doubly-labelled water method), Sagayama et al. [6] showed that the energetic demand of table tennis was underestimated. Using an indirect calorimetry technique, the energetic demand of young elite table tennis player was evaluated at about 8 MET during high-intensity training sessions [7]. As a consequence, table tennis was then found equivalent to other vigorous racket sports [8].

In summary, success in table tennis requires the capability to perform high-intensity efforts and to rapidly recover between rallies and matches, in order to maintain both high physical intensity and cognitive functions all along the tournaments [9]. Due to the intensive and intermittent physiological demand in table tennis, classical cardiorespiratory methods fail to discriminate player level. Hence, further studies could try to assess the energetic demand of table tennis through mechanical energy that may be more relevant to reach this goal because mechanical energy is a direct and instantaneous consequence of the physiological demand, contrary to O_2 and CO_2 exchanges and consumption.

3.3. Neurophysiology

This sub-category included 17 articles mainly focusing on reaction-time, visual perception, auditory and haptic (i.e. kinesthetic) perception, brain activity and eyes-hand coordination.

Regarding reaction-time, some authors showed that both the reaction and response-times to a visual stimulus are shorter for table tennis players than for non-table tennis players [10]. According to the authors, this highlights that elite table tennis players use perceptual, cognitive and motor resources to produce fastest ball motion, which is a key factor to reduce the time available for the opponent to react. Other authors found that elite table tennis players exhibit higher reactivity to stimuli of uncertain location than control subjects [11], suggesting the use of a compensatory strategy by preparing their motor response to high probability events while simultaneously devoting more visual attention to an upcoming event of lower probability. A visual-motor advantage in response-time was also found for subjects having an eye-hand crossed laterality because the functional connection between visual input and motor output only involved one hemisphere [12], saving 30 ms in interhemispheric transfer. Finally, no effect of the personality (introvert vs. extravert) was found on neither reaction-time nor directional aspects of the ball flight [13].

Regarding visual, auditory and haptic perception, it was shown that table tennis players use visual information about the opponent to predict the ball trajectory. According to some authors, these predictions are in favor of current theories of joint action, that is, the common coding theory (i.e. suggests a direct link between observation and execution without needing cognitive processing in-between). In this case, the online control of the arm movement is coupled with visual body information about the opponent [14]. Based on functional MRI, anticipation performances were shown to be improved when visual stimuli are accompanied by auditory stimuli, i.e. racket-ball contact sound [15]. Haptic perception was also shown to be better for elite players compared to novices, especially during self-produced movements, which is explained by the functional variability of haptic afferent subsystems [16]. Some authors evaluated the interest of ball balancing and bouncing for talent detection. However, even if those fundamental skills facilitate learning more specific table tennis skills, they play a limited role in table tennis performance [17]. Also, mental imagery was found to enhance performance even in open skills, and to be more efficient when subjects have to build up mental representation with the appropriate environmental stimulations (such as kinesthetic and auditory) [18].

Regarding brain activity, it was shown that high motor skills in table tennis require high attentional demand, which is associated with focused excitability of the motor cortex during reaction, movement planning and execution. These authors suggest that ''less activation of the fronto-parietal attention network may be necessary to become a world champion'' [19]. In addition, highly skilled individuals were shown to present less cortical activation when elaborated skills become automatic, which refers to the ''neural efficiency hypothesis''. Indeed, expert players appeared to show less desynchronized brain activity in the left hemisphere and more coherent brain activity between fronto-temporal and premotor oscillations in the right hemisphere [20]. These authors hypothesize less interferences of irrelevant verbal-analytical communication with motor control mechanisms. According to these authors, this facilitates the state of flow experience and seems to be related with world rank in expert players. Another study found that elite and sub-elite table tennis players exhibit above average scores on higher-level cognitive functions such as working memory (short-term memory), inhibitory control (capacity to inhibit natural and habitual responses) and cognitive flexibility (ability to switch attention) [21]. Finally, anxiety was found to impair both performance effectiveness and efficiency [22]; and the decrements are more pronounced on working memory under high demands.

Regarding motor coordination, some authors suggest that eye-hand coordination could be used for talent identification [23]. In particular they proposed to test children by asking them to throw a table tennis ball against a vertical table (placed at 1 meter) with one hand and to catch it with the opposite hand as many times as possible in 30 seconds. However, they also suggested that longitudinal studies need to be performed to further evaluate the predictive value of this test. Another study focused on head, eye and arm coordination under different temporal constraints and found that there is a functional coupling between perception and action during time-constrained, goal-directed actions [24]. Adaptations were observed on gaze, head and hand movement depending on the timing of the cues. In a late-cue condition, even expert players' adaptation was not sufficient to preserve their stroke accuracy. Moreover, mental fatigue was found to decrease both ball velocity and accuracy [25]. Aune et al. [26] also showed that professional players stroke accuracy was less affected by fatigue than lower skilled players because they would be able to adapt their gesture, thus soliciting their muscles differently. This change in muscle recruitment would allow the local muscular fatigue to be limited.

3.4. Ophthalmic physiology

Twelve articles were included in this sub-category, mainly focused on visual performances, visual behavior, and visual gaze strategy during a table tennis rally.

Due to high ball velocity and specific trajectories (as a consequence of the ball-spin), table tennis players need to train their ophthalmic skills. Ophthalmologic tests showed that high level players exhibited a better dynamic visual acuity, a wider visual field and a superior recognition of peripheral targets than average people [27]. These skills are useful to high level table tennis players to decrease the amount of information to be processed. The repetition of training sessions leads players to use their peripheral vision to obtain relevant information and to keep fovea vision close to interest areas. By doing so, expert players are able to decrease the amount of fixation points required to create a coherent perceptual representation of the stroke performed by their opponent [28]. High level table tennis players also exhibited better adaptation to the perceptual demands resulting from varied and decelerated ball trajectories [29,30] and to a stimulus velocity in coincidence-anticipation timing. Under high stimulus velocity, table tennis players were found to exhibit higher coincidence-anticipation timing accuracy than tennis and badminton players [31], which could be related to the characteristics of the flying object.

Besides, not all the scene and the action are visualized by the table tennis player because he needs to select critical information among the amount of information available from its environment to provide an adequate response. Expert table tennis players focused their gaze on small areas suggesting enhanced attention on the ball and the opponent, and fewer consideration for the surrounding areas [14,32]. Their spatial variability was also more reduced at the ball and racket contact point rather than at movement initiation [33]. Also, they used fewer fixations of longer duration [28] on areas of interest but with a narrower directional distribution [32]. Gaze is composed with saccades (the place where eyes are fixing the object) and microsaccades which could indicate the places on which the mind is unconsciously focusing on. The study of the microsaccades showed that high level table tennis players exhibited more microsaccades than novice players during the post bounce period but with longer duration and amplitude in order to figure out the opponent's motor action earlier. Finally, the orientation of the microsaccades was conditioned by objects that attracted visual attention and not by the direction in which the action is expected to be performed [34]. Analysis of the visual strategy showed that elite players focused on their opponent's body until ball-racket contact [28]. The fixation on the opponent was obtained systematically during matches but not during forehand sessions. Once the opponent had hit the ball, only the first part of the ball's trajectory was tracked by the player [35]. It was also shown that elite players tracked the ball earlier during the flight and then kept their gaze stable on a predicted location, in advance of the ball before to hitting it [24,36]. Besides, the visual search strategy was different in relation with the nature of the stroke, both on the focus area on the opponent [28] and on the fixation time on the ball [36]. Indeed, during topspin forehand, expert players focus on the distal cues (i.e. arm) whereas they focus on proximal cues (i.e. hand-racket and trunk) during backhand [28]. Also, players tracked the ball more often and for longer periods of time during backhand than during forehand [36].

Finally, Rodrigues et al. [24] showed that performance level depended on the time during which the players focused on where to return the ball, which is called the ''quiet eye duration''. High skilled players can reduce this duration and compensate with a reduction of their arm velocity at impact to maintain a certain level of stroke accuracy. But there is a limit to this duration restriction and a very late information ultimately results in a decrease in the stroke accuracy. Bootsma [33] showed that once these players have started the gesture to return the ball, they do not need additional visual information to finish the stroke. These results mean that the training needs to be as intensive as matches in order to work on taking information at the real temporality.

3.5. Biomechanics

Regarding the 16 papers related to table tennis biomechanics, they were split into three sub-categories: kinematics (9 articles), kinetics (4 articles), and muscle activation (3 articles). Some papers focused on forehand drive (6 articles), some analyzed the backhand drive (4 articles) and other did not specify any information regarding the stroke to perform. Two additional PhD Theses about the mechanical contribution of the arm during backhand topspin [37] and the development of a biomechanical model applied to forehand drives [38] were included. These two PhD Theses were obtained through an additional search on a motor engine. Article quality assessment resulted in a mean grade of 6.3/9 and ranged from 2.5 to 7.5. Overall, the participants are well described but the methods are sparsely or poorly described.

Whatever the focus is, the determination of the motion phases is the first challenge to be addressed for biomechanical analysis. Some authors split the stroke into two phases: backward and forward motion [39,40]. Another author split the movement into three phases: backswing, batting, and waving [41]. Iino et al. [39] used synchronized videos to determine the phases manually. To determine the different phases automatically, Qian et al. [40] used the knee flexion and the hip internal rotation. Others used the racket velocity and position for the detection of those phases [38]. To date, identification of the ball-racket impact remained a challenge and authors generally hypothesized that the ball-racket impact is concomitant with the instant of maximum racket velocity [42].

3.6. Kinematics

Regarding kinematics, few studies (2 articles) focused on the lower limb joints while the other studied the upper-limb joints or the racket (7 articles). Compared to intermediate players, high skilled players exhibited larger hip flexion and knee external rotation at the end of the backward motion; and larger hip internal rotation and extension at the end of the forward motion [40]. Iino [43] demonstrated the relation between the peak value of pelvis axial rotation and the horizontal velocity of the racket. Professional players also exhibited a higher range of motion of their upper limbs than collegiate players, during both backhand [44] and forehand drives [39]. In addition, this higher range of motion was covered in less time for advanced players than for lower skilled players [39], which implies a faster motion of the racket leading to a faster ball [45]. Bańkosz and Winiarski [46] reported angular velocities for the whole body on national junior female players and also showed that racket velocity was related to arm internal rotation and shoulder adduction during forehand drive; and to arm abduction during backhand drive. Differences were observed in both shoulder and foot orientation (with respect to the table) between long-line and cross-court (CC) trajectory shots, with higher angles during long-line shots [47]. Besides, the orientation of the racket was higher in long-line shots, which may be associated to the shot direction. Analysis of time distribution during strokes showed that the duration of the forward motion is not significantly different between players. However, players could extend the total stroke duration by increasing the backswing duration [42]. Finally, it was shown that good players exhibited a higher consistency of racket orientation at ball impact than less skilled players, while exhibiting a higher variability in their joint configuration at impact, which mean a better exploitation of the joint redundancy [48].

3.7. Kinetics

Among the four articles included in this sub-category, two focused on the upper limbs and the other two on the lower limbs. These studies allowed to measure vertical forces up to 1.5 times the body weight during table tennis activity [41]. The power flow through the body was also studied [49—51] and lower limbs joint where found as the primary source of energy during forehand drives [51]. Also, horizontal velocity of the racket was found related to the torque of hip axial rotation on the playing side. This study also suggests that the technique to generate the vertical velocity of the racket may vary among players. Regarding the upper limbs, advanced players exhibited a higher shoulder internal rotation torque than intermediate players during topspin forehand, which allows for more mechanical energy to be transferred from the trunk to the upper arm. The shoulder net joint forces, which peaked just before impact, also provided additional energy to the racket [49]. During topspin backhand drive, against both back- and top-spins, energy transferred by the shoulder joint was the largest contributor to the mechanical energy of the playing arm. Besides, this energy flow was greater against backspin than against topspin (34 and 28%, respectively) [51]. According to these authors, these results suggest that the upward thrust of the shoulder and the late timing of the axial rotation of the upper trunk are important for an effective topspin backhand. It has also been demonstrated that the mass of the racket (ranging from 153.5 g to 201.5 g) did not impact the kinematics or the kinetics of the table tennis topspin backhand [50].

3.8. Muscle activation

Regarding muscle activity during forehand drive, Tsai et al. [52] did not find any difference in EMG maximal amplitude of upper-limb muscles before ball impact between topspin and backspin incoming balls. It was however shown that muscle activity of playing side lower limb muscles depended on the stroke type [53] with higher activity during offensive strokes than during defensive strokes, which would increase muscular fatigue. Other authors [54] showed that experienced players have a lower muscle activity on the lower limbs than amateur players during backspin.

3.9. Injuries

Regarding the search on table tennis related injuries, 10 articles were found and were included into two sub-categories: acute (3 articles) and chronic (7 articles) injuries. Article quality assessment ranged these articles from 2 to 5.5 with a mean grade of 4.6/9 because, if the methods and the patient characteristics were appropriate and generally well described, limitations were often missing.

3.10. Acute injuries

Three papers focused on acute injuries. One of them was a case report about fingers dislocation in a recreational player, which is reported as a rare case (only ten cases in the literature) [55]. The other two were descriptive epidemiology studies during the Summer Olympics Games [56,57] where a low injury incidence was reported for table tennis (0—3%). In these studies, one third of the injuries were estimated to lead to more than one week of absence from sports and less than 5% to more than a month. The proportion of injuries during training sessions was higher in table tennis than during competition and about 50% of diagnoses affected the lower limbs, and 50% affected the upper-body. The most prevalent diagnoses were ankle sprain and thigh strain. The injury localizations were however not reported precisely.

3.11. Chronic injuries

Among the seven articles focusing on chronic injuries, five dealt with the upper limbs. Most of them were clinical cases [58—61] about young players and concerned various playing levels. Kamonseki et al. [62] showed that table tennis players suffer from a deficit of glenohumeral internal rotation on the dominant side but the global rotation was preserved. The relation between shoulder pain and the deficit was however still no elicited. It was also shown that increasing the table tennis athletic activity in few weeks could have an effect on bones, such as a stress fracture of the ulna [59]. One article focused on vertebral column complaints [63] and did not find any relation between the competition and dorsalgia. Finally, only Kondric et al. [64] provided epidemiological data with injuries localizations for top Slovenian racket sport players (table tennis, tennis and badminton). Most of the injuries in top table tennis players were located at the shoulder (about 20% of the reported injuries) followed by the hip and the spine (about 15% each), the ankle (about 13%) and the wrist (about 11%). Unfortunately, the diagnoses were not reported (muscle tissues, joint and tendon injuries, etc.).

4. Discussion

This paper aimed at providing a systematic review on current knowledges of table tennis physiology, biomechanics and injury. Overall, table tennis involves intermittent efforts with short-high-intensity efforts during rallies (about 3.5 seconds in average) interspersed with short resting period between them. It results in a complex physiological demand where — even if the energy covering was mainly ensured by the aerobic system — the phosphocreatine breakdown contribution was found critical for performance. Changes in table tennis rules resulting in a limitation of break durations between rallies would limit the recovery time and therefore lead to changes in table tennis physiology, more especially in an increased contribution of the anaerobic system. Besides, due to this complex physiological demand, specific table tennis physiological tests that were developed failed in being discriminative for performance and to reflect physiology obtain on more classical test on bicycle, treadmill or rowing ergometers. Because mechanical energy is an instantaneous output of the muscular work, biomechanical studies might be more effective to study table tennis physiology. However, such methods require costly instrumentation including force plates and motion capture systems. In addition it would require accurate assessment of body segment inertial parameters of each individual, which currently remain a challenge in the field of biomechanics.

Thanks to their intensive practice, table tennis players exhibit a better reaction-time than non-table tennis players as well as an improved field of vision. Besides, elite players need less visual information than intermediate players, allowing processing time to be spared and to devote longer time to prepare their stroke. Also, during receives, players focus their gaze on their opponent's body and arm in order to predict the incoming ball characteristics. Therefore, table tennis can be considered as an anticipation sport rather than a reaction sport. This underlines the importance of varying sparring-partners/opponents in order to store in mind a maximum of different strokes and to be able to adequately react to many scenarios. Also, table tennis playing robots could not be as useful as expected in table tennis training because they cannot replicate the opponent body motion and the player cannot learn to detect relevant information from the opponent's body. It can however still be an opportunity for footwork training or for fixing technical gesture in young players.

Due to the restricted time between two strokes and the necessity to anticipate the ball trajectory, training sessions need to be as intensive as competition matches. Table tennis requires a high attentional demand, but highly skilled individuals present less cortical activation than intermediate players that is assumed to be related to the state of ''flow experience''. This mental state can only be attained by players for whom strokes became automatic, which requires numerous hours of training. In order to reduce the training load, mental imagery can be an alternative to enhance performance. However, it was shown to be really efficient only in an appropriate kinesthetic and auditory environment.

Biomechanics analysis requires phase detection. This seems to be of particular interest but none of the study agree on the method to determine these phases. In terms of biomechanics, high level players exhibit higher range of motion than intermediate level players on both upper and lower limbs during classical strokes. The hip joint is highly involved in table tennis strokes and a noticeable relation was found between hip joint torques and racket horizontal velocity. Also, the mechanical energy involved in a stroke is mainly produced by the lower limbs. The shoulder joint was found to be the principal contributor to the energy of the playing arm. The high involvement of both the shoulder and the hip in table tennis performance could also be analyzed in regard of the injuries, which mainly occur at these joints (20% for shoulders and 15% for the hips).

Unfortunately, epidemiological studies were rare and, in most of them, the localizations, the diagnoses and the effects on the training or competition calendar of the player were not reported. Those data could be helpful to better understand the apparition of injuries to set up prevention and training care, which would improve performance. Therefore, relation between biomechanics and overuse injuries are difficult to draw.

5. Conclusion

To conclude, many efforts have been made to develop specific physiological tests, but they remain inefficient. Development of energetic methods based on mechanical energy could be interesting to characterize table tennis physiological demand, but it remains a technological challenge. The evolution of table tennis rules tends to reduce resting time, which would modify the physiological demand that would necessitate to be re-evaluated. Research on table tennis biomechanics have been conducted on upper- or lower-limbs but no study had considered the full body and the link between lower limb and upper-body biomechanics during table tennis strokes that would be interesting to make the linkage from the footwork to the racket velocity. Regarding injury analysis, future epidemiological research would have to pay attention on collecting more detailed data than injury location, including diagnoses. These data would be helpful for the physicians and the medical staff to improve the medical and training care.

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Disclosure of interest

The authors declare that they have no competing interest.

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